UCRL-CONF-204796

LAWRENCE
LIVERMORE
NATIONAL
LABORATORY

Rapid Synchronization of Ultra-Wideband Transmitted-Reference Receivers

F. Nekoogar, F. Dowla, A. Spiridon

June 21, 2004

Wireless2004
Calgary, Canada
July 12, 2004 through July 14, 2004

UCRL-CONF-204796

Rapid Synchronization of Ultra-Wideband Transmitted-Reference Receivers

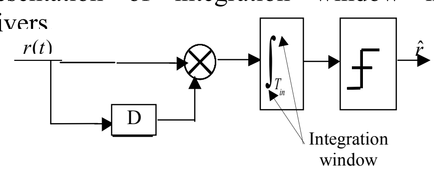
Faranak Nekoogar, Farid Dowla, Alex Spiridon
Department of Applied Science, University of California Davis
Lawrence Livermore National Laboratory
E-mail: {nekoogar1, dowla1, spiridon1}@llnl.gov

Abstract- **Time synchronization is a major challenge and a rich area of study in ultra-wideband (UWB) communication systems. Transmitted–reference (TR) receivers avoid the stringent synchronization requirements that exist in conventional pulse detection schemes. However, the performance of such receivers is highly sensitive to precise timing acquisition and tracking of integration window that defines the limits of the finite integrator prior to final decision block. In this paper we propose a novel rapid synchronization technique that allows us to extract the timing information very accurately in UWB-TR receivers in the presence of a variety of channel noise and interference. The principles of the method are presented and the BER performance of a synchronized UWB-TR receiver is investigated in the presence of a range of values for timing jitter by computer simulations. Our studies show that the proposed synchronization technique greatly improves the performance of UWB-TR receivers in the presence of jitter and AWGN with modest increase in complexity.**

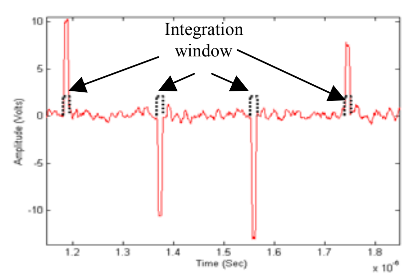
Keywords: Transmitted-reference (TR), ultra-wideband (UWB), timing jitter, interference mitigation, synchronization, acquisition, tracking.

I. INTRODUCTION

Ultra-wideband (UWB) communication systems offer very high data rates by the transmission of pulses with very short duration and low duty cycles. The strict power limitations and short pulse duration make the performance of UWB systems highly sensitive to timing errors. Therefore, time synchronization introduces a major challenge in such systems [1-2]. The challenge posed by synchronization of narrow, low powered UWB pulses has been addressed to some extent by transmitted-reference (TR) modulation. TR modulation [3-4] avoids the stringent synchronization requirements that exist in conventional pulse detection techniques by eliminating the need for individual pulse synchronization with locally generated templates. However, the performance of TR receivers is largely dependent to accurate timing acquisition and tracking of the integration window in the presence of channel noise. Fig. 1 provides a representation of integration window in TR receivers



(a)



(b)

Figure 1: Representation of integration window in (a) TR receivers (b) Received signal in a noisy LOS channel

The integration window introduces two important design parameters; *length of integration interval* and *accurate timing of integration interval*. The length of integration interval plays a major role in the performance of UWB-TR receivers in both LOS and NLOS channels. In LOS channels, if

This work was performed under the auspices of the U.S. Department of Energy by University of California Lawrence Livermore National Laboratory under contract No. W-7405-Eng-48.

.

integration interval is smaller than the pulse width, only a fraction of pulse energy is collected, introducing more degradation than the gain achieved by the decrease in noise and results in a net decrease of the output SNR. Similarly if integration interval is larger than pulse width, larger amount of noise is introduced hence, noise energy builds up with no additional signal energy and causes a decrease in output SNR. Therefore, the integration interval should be equal to pulse width in LOS channels to capture most of the pulse energy. Optimal integration interval for multipath channels is studied in [5-6].

The accurate timing acquisition and tracking of integration window for each received bit is another important factor in the performance of UWB-TR receivers that has not been explored yet. Any deviation from the precise position of integration window causes a decrease in SNR of the detected bits and results in false alarm and severe performance degradation of the receiver. In this paper, we present a novel algorithm for rapid acquisition and tracking of the integration window in TR receivers. The proposed method efficiently processes the incoming signal and suppresses various types of non-UWB interference to provide accurate integration window acquisition and tracking prior to data decoding. The method involves introducing an interference mitigation mechanism to enhance the SNR of the received pulses in a conventional TR receiver for obtaining accurate timing acquisition and tracking of integration window. The organization of this paper is as follows. Section II briefly reviews the TR receiver structure as a basis for new synchronization method studies. Section III presents the rapid synchronization method based on introducing an interference mitigation mechanism to conventional TR receiver structure. Concluding remarks are summarized in Section IV.

II. TR RECEIVER OVERVIEW

The basic building block for a TR modulated waveform is a pair of pulses or doublets consisting of an unmodulated reference pulse followed by a modulated transmit pulse, separated in time by "*D*" interval. The individual pulses forming the waveform, can be any one of a variety of wideband pulses, such as Gaussian, chirp, or hermite based short duration pulses. Data is modulated based on the relative polarity of the reference and transmit pulses. For instance a reference and a transmit pulse of the same polarity designates a binary value of "1", while a transmit pulse opposite in polarity with reference pulse corresponds to a binary value of "0".

TR reception and demodulation scheme relies on the correlation between the received signal with its delayed replica as shown in Fig. 1a. Delaying the received signal by *D* causes the reference pulse to align with the transmit pulse in each symbol. The product of these aligned pulses followed by a finite integrator captures the energy in *lag zero* of the generated autocorrelation function. Finally the captured energy will be translated to binary data by a hard decision device.

One of the major advantages of UWB-TR receivers over the conventional pulse detection techniques is self-synchronization. TR receivers avoid the strict synchronization requirements since each reference pulse in a TR symbol acts as a preamble for the transmit pulse. Furthermore, synchronization in such receivers occurs after correlation between the reference and transmit pulses, thus the sampling requirements are relaxed to baseband signals. This way, the need for synchronization of the received short duration RF pulses and very fast and expensive ADCs are eliminated. However, a major disadvantage of TR receivers is the noise-on-noise interference [7] between the reference and transmit pulses that can produce false recognition of the synchronization in the presence of channel noise or intentional jamming. Therefore, precise acquisition and tracking of the integration window in noisy channels is the key requirement to successful synchronization in UWB-TR receivers.

III. SYNCHRONIZATION STRATEGY

The proposed synchronization strategy is based on introducing two additional units called SNR Enhancing and Acquisition/Tracking to conventional TR receiver structure. Fig. 2 represents the block diagram of a modified TR receiver with rapid synchronization capability.

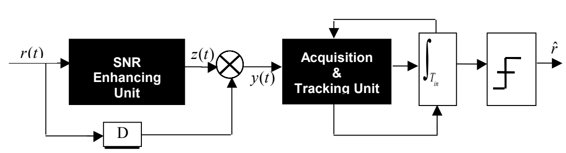


Figure 2: Block diagram of a TR receiver with rapid synchronization

The SNR enhancing unit provides interference suppression to TR receivers through a feedback loop mechanism and improves the signal-to-noise-ratio of the reference pulses for initial acquisition of the integration window. Once the SNR is enhanced, the strong signal, $z(t)$, will be multiplied with a delayed version of the original received signal, $r(t)$ as

$$y(t) = r(t - D).z(t) \tag{1}$$

At this point the acquisition and tracking unit estimates the start and end of the integration window, T_{in}, for each received bit prior to finite integration operation. Therefore, the received data bit can be decoded as

$$\hat{r} = \text{sgn}\left(\int_{T_{in}} r(t - D).z(t)dt\right) \tag{2}$$

The details of each unit are discussed in the following subsections.

1. SNR Enhancing Unit

The SNR enhancing unit actively suppresses various types of non-UWB interference in TR receivers while preserving the desired UWB signal. Fig. 3 shows the details of the SNR enhancing unit.

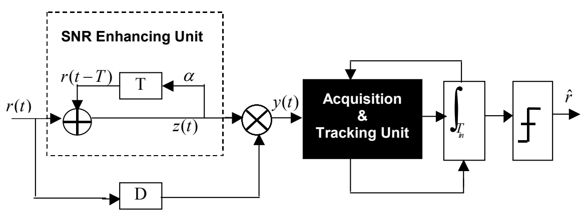


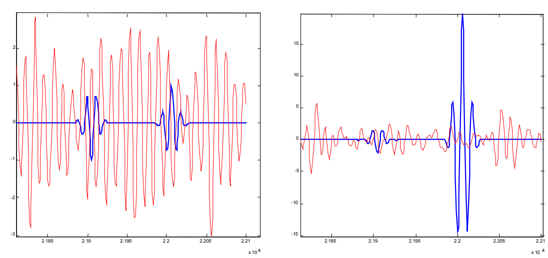
Figure 3: SNR enhancing unit in TR receivers with rapid synchronization

Interference mitigation is achieved by introducing a feedback loop mechanism to enhance the reference pulses in TR doublets. The feedback loop contains an averaging delay, T, equal to the symbol repetition period and a loop gain α smaller than 1. A gain of less than one introduces a loss factor for processing gain of the combined noise and signal associated with loop iterations. Such adjustment of the gain results in noise signals circulating in the loop along with the desired signals to incur an increment of loss. This loss is often adjusted to the maximum value while assuring loop stability. The lower the loop loss the longer would the loop retain a pulse, hence the larger number of pulses that are averaged. As shown in Fig. 3, the received signal goes through multiple iterations around the feedback loop. With the loop delay, *T*, set to the symbol repetition period, the reference pulses captured in each iteration will overlap and their signal power is enhanced each time. Therefore, $z(t)$ and $\hat{r}$ in (1) and (2) can be expressed as

$$z(t) = \sum_{k=0}^{K} \alpha^k r(t - kT) \tag{3}$$

$$\hat{r} = \text{sgn}\left(\int_{T_{in}} r(t - D).\sum_{k=0}^{K} \alpha^k r(t - kT)\,dt\right) \tag{4}$$

This mechanism works based on the assumption that interference is uncorrelated with signal, hence each circulation of input signal through the feedback loop makes reference pulses cleaner by rejecting the interference. Please note that the feedback loop mechanism only improves the SNR of reference pulses, since transmit pulses may have opposite polarity depending on the transmitted data and may not experience the same resonance all the time. Fig. 4 shows an example of reference pulse cleaning in a transmission channel consisting of AWGN and multiple narrowband jamming signals.



(a) (b)

Figure 4: Reference pulse cleaning in a transmission channel consisting of AWGN and NBI. (a) An UWB TR doublet (solid lines) in the presence of strong interference (dotted lines). (b) Cleaned reference pulse after 100 loop iterations with α=0.95. Note, transmit pulse has not experienced the resonance.

As shown in Fig.4 the signal-to-interference ratio of reference pulse in a TR doublet increases significantly as the number of loop iterations increases. This method always works well for signals corrupted by AWGN channels, since different samples of white noise are uncorrelated, although some correlation will be introduced by the feedback loop filter. Further, for a successful narrowband interference rejection, *T* should not be equal to integer multiples of interfering narrowband signal period to avoid resonating the interference [8].

2. Timing Acquisition and Tracking Unit

The acquisition and tracking units consists of a threshold detecting comparator and a counter circuit. Fig. 5 shows the acquisition and tracking unit in modified TR receivers.

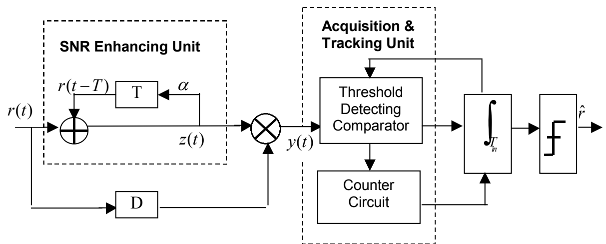


Figure 5: Acquisition and tracking unit in TR receivers with rapid synchronization

The initial acquisition of the integration window is performed by a comparator device that is programmed to detect various values of signal power in dB units. Once the first reference pulse in the received signal passes the assigned threshold, the initial acquisition takes place and results in partial synchronization of the receiver. The fine synchronization or tracking operation starts by searching for the specified threshold every T units in time to maintain the synchronization and integration window estimation through the duration of the transmission. The initial acquisition and tracking algorithm can be summarized as

1. $y(t) = r(t-D).\sum_{k=0}^{K} \alpha^{k} r(t-kT)$

2. If $\dfrac{\int y^2(t)}{\int noise^2(t)} \geq$ *specified threshold in dB*

3. $T_{in}^{(1)} = T_1 \,\&\, T_2$ *(initial acquisition of integration window)*

4. $T_{in}^{(m)} = \begin{cases} T_1 + \sum_{m}^{M=No\,f\,bits} m.T \\ T_2 + \sum_{m}^{M=No\,f\,bits} m.T \end{cases}$ *(Tracking of integration window)*

5. Else (k=k+1)

6. Repeat steps 2, 3, and 4

The initial acquisition of the received pulses involves some search for the first signal with SNR of larger than the specified threshold. However, this search ends quickly after 15 or 20 loop iterations as the SNR improves rapidly and initial acquisition is achieved. This method is much faster than the exhaustive search algorithms conventionally used for pulse synchronization. Fig. 6 illustrates the SNR enhancement in TR receivers using the feedback loop mechanism.

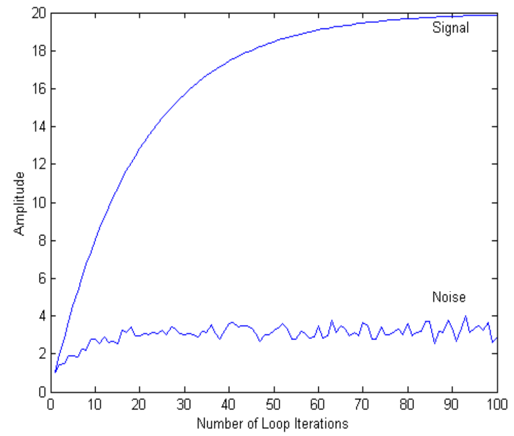


Figure 6. Amplitude versus number of loop iterations for TR receiver with feedback loop SNR enhancing mechanism

As shown in Fig. 6, the signal amplitude rapidly improves after very few loop iterations while the noise amplitude stays relatively constant. This is due to the fact that noise is uncorrelated in time and overlap of reference pulses does not create correlation between noise samples. Fig. 7 shows the BER performance of a synchronized TR receiver based on various number of loop iterations.

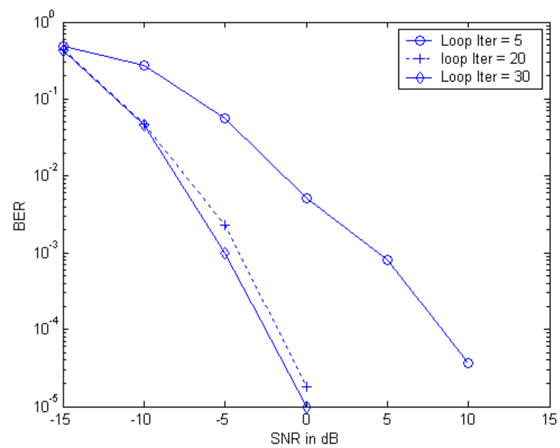


Figure 7. BER versus SNR performance of a synchronized TR receiver based on various number of feedback loop iterations. High performance is achieved after 20 iterations and saturates for higher number of loop iterations at SNR=10 dB threshold

As demonstrated in Fig. 7, the synchronization with high performance is achieved after only 20 iterations for 100000 transmitted bits used in computer simulations. Fig. 8 shows the performance of the same receiver in the presence of a range of jitter values.

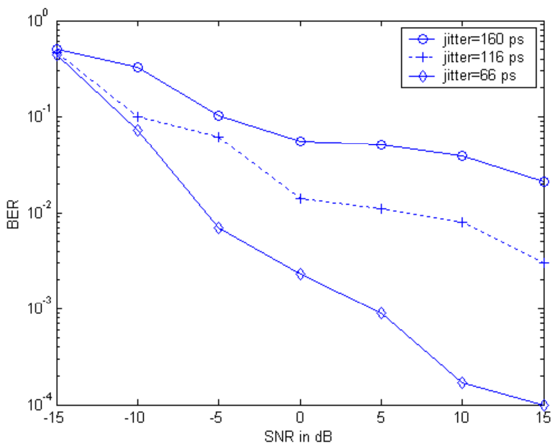


Figure 8. BER versus SNR performance of a synchronized TR receiver at SNR=10 dB threshold and 20 loop iterations in the presence of a range of values for jitter

This Figure demonstrates that the proposed synchronization algorithm for TR receivers performs well in the presence of jitter. The jitter of up to 66 pSec is tolerated for 8 nSec pulses used in our simulations.

IV. CONCLUSIONS

A novel and simple synchronization method employing an interference mitigation mechanism to enhance the signal-to-noise-ratio of the received TR modulated signals is proposed in this paper. This method enhances the received pulses SNR and accurately estimates the integration window to detect each data bit. The BER versus SNR performance of a TR receiver with the proposed synchronization technique is evaluated based on various parameters of the interference mitigation unit. The analysis reveals that the proposed synchronization method has proven to be effective for providing high BER performance in UWB TR receivers at the presence of various types of non-UWB channel interferences and large values of jitter. The method can be extended for synchronization of a multiuser system by assigning a unique symbol repetition period, *T*, to each channel.

REFERENCES

[1] I. Maravic, J. Kusuma and M. Vetterli,"Low-Sampling Rate UWB Channel Characterization and Synchronization" Journal of Communications and Networks, special issue on UWB systems, Vol. 5, No. 4, pp. 319-327, December 2003.

[2] I. Maravic, M. Vetterli and K. Ramchandran, "Channel Estimation and Synchronization with Sub-Nyquist Sampling and Application to Ultra-Wideband Systems," invited paper, ISCAS 2004.

[3] R. Hoctor, H. Tomlinson, "Delay-hopped Transmitted-Reference RF Communications", 2002 IEEE Conference on Ultra Wideband Systems and Technologies, May 2002.

[4] R. Hoctor, H. W. Tomlinson, "An overview of delay-hopped transmitted-reference RF communications," GE Research and Development Center, Tech. Rep. 2001CRD198, 2002.

[5] S. Franz, U. Mitra, " Integration interval optimization and performance analysis for UWB transmitted reference systems," ICC 2004.

[6] S. Franz, U. Mitra, "Transmitted reference systems for UWB communication systems", IEEE Trans. Comm. (to appear).

[7] A. Spiridon, F. Dowla, F. Nekoogar, D. Benzel, " On the performance of ultra-wideband transmitted-reference receivers", IEEE Trans. Comm. (to appear).

[8] F. Dowla, F. Nekoogar, F. Spiridon, "Interference Mitigation in Transmitted-Reference Ultra-Wideband Receivers", IEEE International Symposium on Antennas and Propagation (APS 2004), Monterey, CA June 20-26, 2004.

[9] C. Carbonelli, U. Mengali, U. Mitra, "Synchronization and channel estimation for UWB signals" Global Telecommunications Conference, 2003. GLOBECOM '03. IEEE ,vol. 2 , 1-5 Dec.2003

[10] G.D. Hingorani, "A transmitted-reference system for communication in ranom or unknown channels," IEEE Trans. Comm. Theory, vol. 13, no.3, pp. 293-301, sep. 1965.

[11] C.K. Rushforth, "Transmitted-reference techniques for random unknown channels," IEEE trans. Information Theory, vol.10, no. 1, pp.39-42, Jan. 1964.

[12] J. Foerster, E. Green, S. Somayazulu, D. Leeper, "Ultra Wideband Technology for Short –or Medium-Range Wireless Communications", Intel Technology Journal Q2, 2001.

[13] Y.C.Yoon, R. Kohno, "Optimum multi-user detection in ultra-wideband (uwb) multiple access through ISI channels, " Proceedings of the IEEE International Conference on Communication, 2002.

[14] M.Z. Win, R. A. Scholz, "Impulse radio: how it works," IEEE Communications Letter, vol . 2, pp. 51-53, Feb. 1998.

[15] R.A. Scholz, M.Z. Win, "Impulse radio," IEEE PIMRC, 1997.

[16] J.D. Choi, W. E. Stark, "Performance of Autocorrelation Receivers for Ultra-Wideband communications with PPM in Multipath Channels", IEEE Conference on Ultra Wideband Systems and Technologies, 2002.

[17] M. Ho, S. Somayazulu, J. Foerester, S. Roy, "A differential detector for ultra-wideband communication systems," IEEE VTC, vol. 4, pp. 6-9, May. 2002, Birmingham, AI.